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Plasmonic resonance in planer split ring trimer

Haiqing Xu [a,*], Hongjian Li [b], Gang Xiao [a]

[a] Department of Mathematics and Physics, Hunan Institute of Engineering, Xiangtan 411101, China
[b] College of Physics Science and Technology, Central South University, Changsha 410083, China

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ABSTRACT

We have numerically investigated the plasmon properties supported by asymmetry planer split ring trimer structures. We investigate the modification of gap distance, thickness and gap width on the transmission properties of the weak coupling model (g is larger than or equal to 120 nm, $d=48$ nm, t is larger than 30 nm, $w_1=200$ nm, and $w_2=40$ nm), as the coupling becomes weaker, the first peak sharply attenuates, the second peak slightly decreases, the transmission dip in the near-infrared region becomes shallow, and they are very sensitive to the gap distance between two small split ring pairs and the thickness and gap width of the big split ring. We also study the change of gap distance on the strong coupling model (g is smaller than or equal to 40 nm, $d=24$ nm, $t=10$ nm, $w_1=80$ nm, and $w_2=20$ nm), there exists a new Fano resonance peak, the strongest peak in visible region becomes symmetry, while the peak in near-infrared region becomes asymmetry. The resonator design strategy opens up a rich pathway for the implementation of optimized optical properties for specific applications.

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1. Introduction

Recently, metamaterials as artificial composite microstructures have received increasing attention because electromagnetic properties can be controlled at will by adjusting geometry parameters for structure cells, which opens a new way to manipulate the novel properties of electromagnetic wave in metamaterials. Very recently, metamaterials are engineered to simulate some quantum phenomena, such as EIT effect and Fano resonance. A Fano resonance can emerge when two resonance mode coupling and the destructive interference can suppress the resonance absorption and thus lead to the Plasmon induced transparency effect (PIT) [1]. A number of nanostructures have been proposed and demonstrated to realize PIT, such as dipole antennas [2–4], detuned electrical dipoles [5,6], split ring resonators [7–10], and plasmonic-waveguide system [11]. This PIT usually accompanies with strong dispersion, which brings many important applications in switching [4,12], slow light [13], and sensing applications [14].

It is worth noting the work presented by Chen et al. [8], they demonstrated that asymmetric coupling within a pair of split-ring resonators introducing an transmittance peak which stem from the asymmetrically coupled resonance. While Li et al. [9] investigated the planer terahertz metamaterials composed of three u-split-rings, they found that when the superradiant and the subradiant resonators brought closer than a critical distance, the PIT peak disappear.

Though so many research works have been done about the planer split ring structures, to our knowledge, there is no report about the plasmon properties of the asymmetry planer split ring trimer which is formed by two small split rings pair and a big split ring up to now. In this paper, we study the optical properties of these structures. The remainder of the paper is organized as follows. In Section 2, the structures and the FDTD method is briefly introduced. In Section 3, the optical properties of the weak and strong coupling asymmetry planner split ring trimers are analyzed in detail. The influence of the parallel and vertical gap distance, the thickness and the split gap width on the transmission spectra for the weak coupling scheme are investigated, in addition, the influence of the parallel and vertical gap distance on the transmission properties and electric field distributions for the strong coupling scheme are also investigated. Finally, the conclusions are presented.

2. Model and method

The asymmetry planer split ring trimer under consideration is illustrated in Fig. 1, the design of this structure is motivated by Refs. [8,9] but it is obviously different from the physical. The longer and shorter of outer side lengths of small and big split rings are denoted by L_1, L_2, L_3 and L_4, the thicknesses of big and small split rings are t_1 and t_2, the parallel distance between the two small split rings is d, the vertical gap distance between the small split

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[*] Corresponding author. Tel.: +86 73158683584; fax: +86 73158683584.
E-mail address: Xu_hq2011@163.com (H. Q. Xu).

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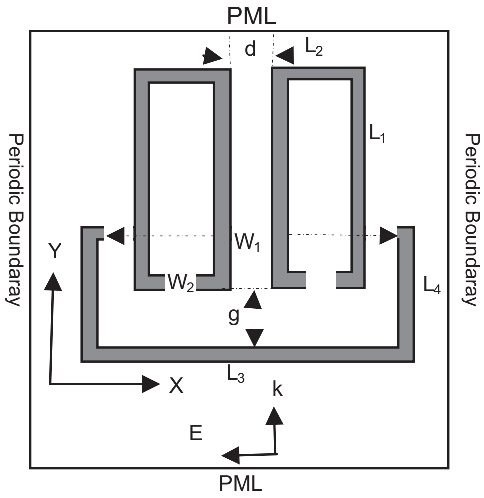

Fig. 1. Top view of the cross section of the asymmetry planner split ring trimer.

ring pair and big split ring is expressed by g, the gap widths of the big and small split rings are w_1 and w_2.

The two-dimensional FDTD method is employed in this work [15]. The frequency dependent optical properties of the gold nanostructures are approximated by the Drude model, which defined the dispersive permittivity as$\varepsilon(\omega)=1-\omega_p^2/(\omega^2+i\omega\gamma_p)$, where $\omega_p=1.37\times10^{16}$ is the bulk plasmon frequency of the gold, ω is the angle frequency of the incident wave, and $\gamma=4.08\times10^{13}s^{-1}$ represents the damping rate which characters the ohmic absorption loss. These values are obtained by fitting the experimental results [16]. And the calculated region is truncated by using perfectly matched layer (PML) absorbing boundary conditions on the top and bottom boundaries of the computational space along the y direction. The left and right surfaces along x direction are treated by periodic boundary conditions. The incident light is along the y direction with TM polarization.

3. Results and discussion

3.1. Weak coupling model

When the small split ring pair and the big split ring have no vertical overlap ($g>110$ nm), the coupling is weak. During the process, we keep the outer side lengths $L_1=200$ nm, $L_2=80$ nm, $L_3=280$ nm and $L_4=120$ nm fixed.

First, we consider the influence of the gap distance d on the resonance properties, while $g=120$ nm, $t_1=t_2=20$ nm, $w_1=200$ nm and $w_2=20$ nm remain the same. As shown in Fig. 2, when $d=24$ nm, in the visible and near-infrared wave band, there are three obvious and sharp peaks, among them, the middle peak is the widest and strongest, also there are four obvious transmission dips. As d increasing from 24 nm, 32 nm, 40 nm to 48 nm, the coupling between the small split rings pair becomes weak, the three transmission peaks blue-shift, the first peak weakens and narrows quickly, the second peak slightly attenuates and narrows, while the third peak enhances and widens instead. When $d=32$ nm, the second and third peak intensities are almost the same, when d continue to increase, the third peak becomes the widest and strongest, which means that the formation mechanism of the third peak and the former two peaks is different. And it is interesting to find that the trend of change of the second and third peaks is similar with the three cut wires model when the middle cut wires L_2 modifying [3]. This is because the second peak mainly results from the coupling of the two small split rings, while the third peak results from the coupling of the two small split rings and the big split ring. With the increase of d, the coupling between the two split rings becomes weaker, whereas their coupling with the big one becomes stronger, so this peak gets more pronounced. During the process, the position of the first and the fourth dips almost not move. The second dip slightly blue-shifts and becomes shallows, which results from a lower absorption when d increases. The third dip sharply blue-shifts and deepens. Compared with the transmission spectra of $d=24$ nm and 48 nm, it demonstrated that the second peak and third dip have exchange trend, which means that the nanostructure has potential application value in light switch.

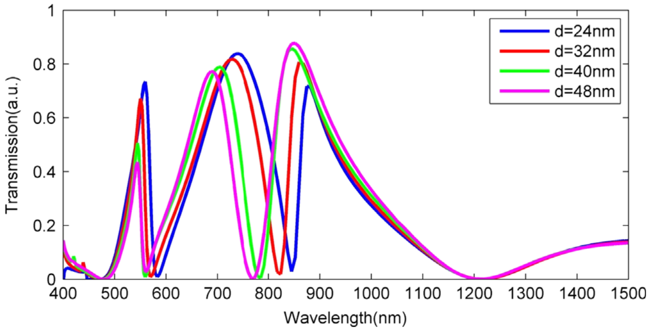

Fig. 2. Transmission spectra as a function of wavelength with different gap distances $d=24$ nm, 32 nm, 40 nm and 48 nm.

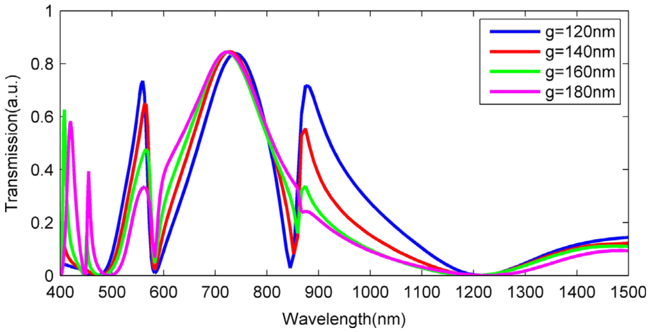

Fig. 3. Transmission spectra as a function of wavelength with different gap distances $g=120$ nm, 140 nm, 160 nm and 180 nm.

Then the influence of the vertical distance between the big split ring and the two small split ring pair is investigated. Fig. 3 shows the transmission spectra as a function of wavelength with $d=24$ nm, $t_1=t_2=20$ nm, $w_1=200$ nm, $w_2=20$ nm, with different vertical gap distances $g=120$ nm, 140 nm, 160 nm and 180 nm. When $g=120$ nm, there exist three sharp peaks, as g increases from 120 nm, 140 nm, 160 nm to 180 nm, the first peak red-shifts and attenuates monotonically, the second dip slightly becomes shallow, the second peak slightly blue-shifts, the third peak blue-shifts and attenuates, while the third dip sharply becomes shallow. When $g=180$ nm, the third peak almost disappears at the wing of the second peak, which because g is too large, the coupling between the two small split rings pair and the big split ring is too weak to format the peak. It is interesting to find that when $g=160$ nm, a sharp strong and a small peaks exist on the left side of the first peak, when g reach to 180 nm, the two new peaks both red-shift, and the left one slightly attenuates, but the right one enhances instead.

Fig. 4 shows the transmission spectra as a function of wavelength with $d=24$ nm, $g=120$ nm, $t_2=20$ nm, $w_1=200$ nm, $w_2=20$ nm, with different big split ring thicknesses $t_1=10$ nm, 20 nm, 30 nm and 40 nm. It found that the thickness of the large split ring has great influence on the spectra, when $t_1=10$ nm, in the visible region there are four continuous peaks, among them the peak near 500 nm is the strongest, in the near-infrared region

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